Presentation

A PRELIMINARY INVESTIGATION OF AEROGRAVITY ASSIST AT TRITON FOR CAPTURE INTO ORBIT ABOUT NEPTUNE

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ABSTRACT

Previous work by our group has shown that an aerogravity assist maneuver at the moon Triton might be used to capture a spacecraft into a closed orbit about Neptune if a nominal atmospheric density profile at Triton is assumed. The present study extends that work and examines the impact of atmospheric dispersions, especially important in light of the very low density and large degree of uncertainty of Tritons atmosphere. Additional variables that are analyzed in the current study include ballute size and cut time and variations in the final target orbit. Results indicate that while blunt-body, rigid aeroshells penetrate too closely to the surface to be practical, ballutes of modest size show promise for this maneuver. Future studies will examine the application of inflatable aeroshells and rigid aeroshells with higher lift-to-drag ratios such as biconics and lifting bodies.

INTRODUCTION

Aerocapture has been studied for numerous missions, primarily focusing on Titan, Mars and Neptune. At the giant planets, these maneuvers inherently involve very high atmospheric entry speeds, severe aerothermal heating rates, and large ablative heat shields. Recent studies indicate that a direct aerocapture at Neptune will typically require aeroshell mass fractions in excess of fifty percent (ref. 1), resulting in a relatively small usable payload. Our group has previously shown that aerogravity assist (AGA) using Titan is promising as a means of capturing a spacecraft into a closed orbit about Saturn (ref. 2,3) This method permits much lower atmospheric entry speeds and will likely produce considerably lower aerothermal heating rates than a direct aerocapture at one of the giant planets. The present study considers the use of a similar maneuver at Triton to capture a spacecraft into orbit about Neptune.

METHODOLOGY

Atmospheric entry trajectories were calculated using the three degree of freedom version of the
Program to Optimize Simulated Trajectories (POST, ref. 4). The atmosphere models used were derived from a stellar occultation studies (ref. 5) and used an atmospheric height of 95 km. Figure 1 shows the atmospheric models that were used in performing simulations for this study. While the degree of potential variability in Triton's atmospheric density is not well known, there is evidence that temporal changes in the sub-solar latitude result in greater or lesser amounts of the atmosphere being condensed onto the surface in a frost-like state. The last two decades have seen a general global warming at Triton and a concomitant increase in the atmospheric density (ref. 6,7) This lead to our choice of density dispersions which are somewhat greater than are typically used for preliminary aerocapture studies.

For this preliminary investigation, all trajectories were simulated using due east, equatorial trajectories. A probe mass of 600 kg was used for these simulations with the overall mass varying slightly according to ballute size. A toroidal ballute was assumed, using a coefficient of drag (C_D) of 1.25; the ballute area was varied from 100 m^2 to 1500 m^2. The attached non-

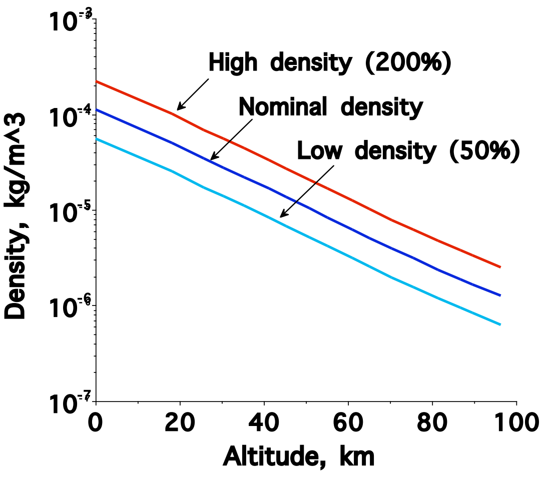

Figure 1 Triton Atmospheric Model

lifting probe had a reference area of 12.56 m^2 and a C_D of 1.25. As a means of comparison, some trajectories

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were calculated using a blunt body with a lift-to-drag ration (L/D) of 0.25, a mass of 600 kg and a reference area 12.56 m^2.

For this study, the nominal case is targeted to an exit velocity of 3.0 km/s. If this velocity is directed opposite to Triton's orbital velocity vector, it will result in a spacecraft orbit about Neptune with a periapse radius of 29000 km and an apoapse at Triton's orbital distance (355,000 km). This design is consistent with previously established mission profiles and reflects current science objectives (ref. 1). Triton entry speeds from 4.7 km/s to 22 km/s were examined in this paper, corresponding to the hyperbolic excess speeds required for Neptune entries over the previously established range of 24 to 34 km/s (ref. 1).

Our initial approach was to determine if the proper amount of energy could be dissipated by a given vehicle during an atmospheric pass. For a rigid, lifting aeroshell, the maximum energy loss for a given entry state will be achieved by flying the vehicle on a full lift down trajectory. The entry angle which achieves the target exit energy for such a full lift down pass is known as the overshoot boundary. This is the shallowest angle at which the vehicle can enter and execute a successful maneuver. For a ballute (which has no lift), the shallowest entry will be achieved when the ballute is held throughout the atmospheric

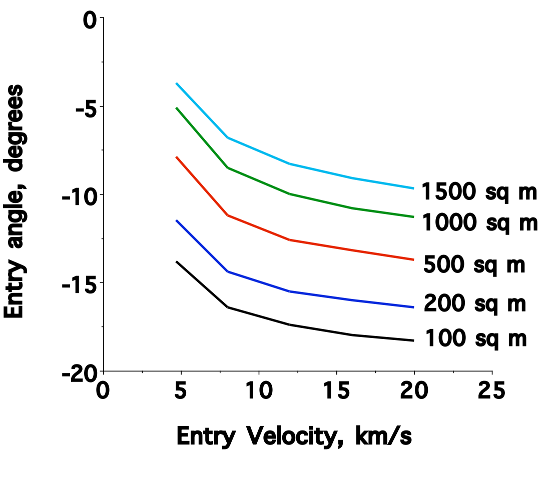

Figure 2. The required atmospheric entry angle as a function of atmospheric entry speed for a range of ballute sizes. The ballute is not released during the atmospheric passage. A nominal density profile is assumed.

pass, rather than being released at some intermediate time. Steeper entries will require the ballute to be released at some earlier time, with the steepest allowable angle set either by heating constraints on the probe or (more probably) on the ballute material or possibly by minimum altitude constraints on the probe after the ballute releases.

RESULTS

Rigid Aeroshell

Trajectory simulations reveal that the rigid aeroshell penetrates to an altitude of 8 km even for the overshoot trajectory flying in the nominal atmosphere. For the low-density atmosphere, steeper entries would be required and these would result in closer approaches to the ground, leaving inadequate margin for error. At entry speeds of 10 km/s or more, capture to the target orbit was impossible since steeper flight path angles were required and these lead to vehicle crashes. These results indicate that blunt body, rigid aeroshells are not suited for this application.

Ballutes

Figure 2 illustrates that throughout the range of potential entry speeds, the correct amount of energy can be dissipated by a wide range of non-releasing ballutes. Figure 2 also shows the sensitivity of the entry angle with respect to the ballute size. Figure 3 shows the relationship of atmospheric exit velocity to the entry angle for a 500 m^3 non-releasing ballute at several specific entry speeds. While it is clear that the exit velocity becomes increasingly sensitive to entry angle as entry speed goes up. it must be noted that these sensitivities will be significantly reduced by allowing for a releasing ballute.

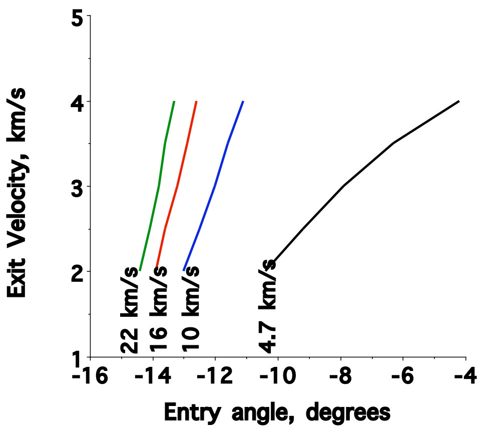

Figure 3 Exit velocity vs entry angle for a non-releasing 500 m^2 ballute entering at various speeds

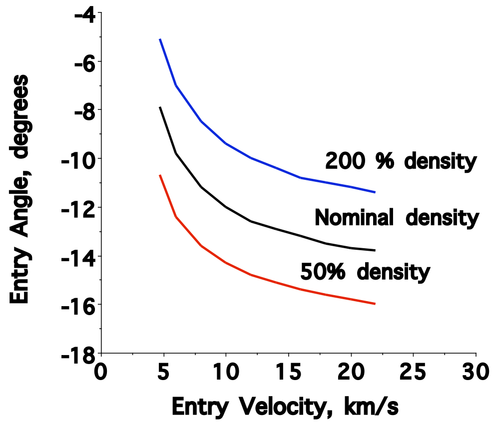

Figure 4 Impact of atmospheric dispersions on required entry angle for a 500 m^2 non-releasing ballute

Another major concern in performing such a maneuver is whether or not trajectories can be achieved while allowing for potential atmospheric dispersions. Figure 4 shows the variation in the required entry angle for a non-releasing, 500m^2 ballute in all three atmospheres.

The extreme density atmospheres do cause some appreciable differences in the required atmospheric entry angles for a non-releasing ballute, but again, this impact would be minimized by allowing for an early release.

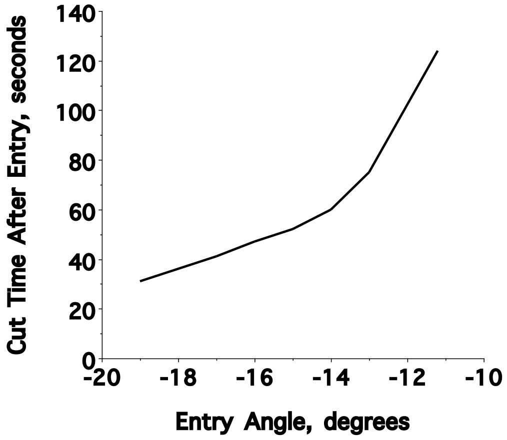

Figure 5. Cut time for a 500m^2 ballute entering the nominal atmosphere at 8 km/s

This approach is illustrated in Fig. 5 where it is clear that a wide range of entry angles can be accommodated by varying the ballute release time.

Conclusions

Aerogravity assist at the Triton-Neptune system is probably not feasible using blunt body, rigid aeroshells with low lift-to-drag ratios. The significant potential variability in the atmospheric density and the low minimum altitudes reached in the aeroshell trajectories will almost certainly result in a failure. However, it appears that the family of ballutes used in this study stays high enough in the atmosphere and offer substantial corridor widths to warrant further study.

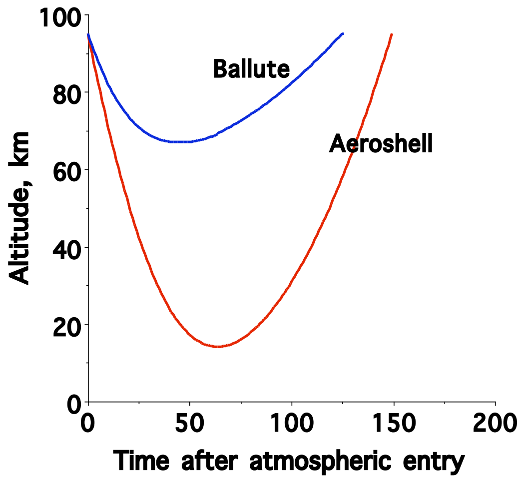

Figure 6. Overshoot trajectory altitude histories for a ballute and a rigid aeroshell entering at 8 km/s

Future Work

More work must be done to more clearly determine the degree of potential atmospheric variability the atmospheric models. Once this is accomplished, it will be necessary to examine the aeroheating environment and design trajectories for both nominal and off nominal atmospheric conditions which meet the constraints of inflatable materials.

Another interesting area to examine will be the use of high L/D, rigid aeroshells (biconics or lifting bodies) and low ballistic coefficient aeroshells, such as those with inflatable skirts to perform the maneuver.

The approach and departure geometry with respect to both Triton and Neptune must be more fully evaluated to determine desirable encounter turn angles.

Acknowledgements

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References

1) Lockwood, M.K., Neptune Aerocapture Systems Analysis, *AIAA Atmospheric Flight Mechanics Conference and Exhibit*, Providence, Rhode Island, AIAA 2004-4951, August 16-19, 2004.

2) Ramsey, P. and Lyne, J.E., "An Investigation of Aerogravity Assist at Titan and Triton for Capture into Orbit About Saturn and Neptune," presented at the 2nd International Planetary Probe Workshop, Moffett Field, California, Aug. 2004.

3) Ramsey, P. and Lyne, J.E., "An Investigation of Titan Aerogravity Assist or Capture into Orbit About Saturn," AAS Paper AAS-03-644, presented at the AAS/AIAA Astrodynamics Specialists Conference, Big Sky, Montana, Aug. 2003.

4) Brauer, G.L, et. al.,"Program to Optimize Simulated Trajectories (POST)," NASA Contract Report NAS1-18147, September 1989.

5) Elliot, J.L. et al, "The Prediction and Observation of the 1987 July 18 Stellar Occultation by Triton: More Evidence for Distortion and Increasing Pressure it Triton's Atmosphere," *Icarus,* 148, pp.347-369, 2000

6) Elliot, J.L., "Global Warming on Triton," Nature, 393, pp. 765-767.